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SUMMARY

Problem.

Countermeasure devices need to be identified to control the high level of individual heat strain associated with shipboard firefighting (Bennett et al., 1993a). Bennett et al. (1993b) reported that a 6-pack torso cool vest reduced heat strain a greater amount than a 4-pack vest during rest and exercise in warm/humid air. However, the 6-pack vest did not fit comfortably under the firefighting ensemble (FFE). Subsequently, Hagan et al. (1994) reported that a small 4-pack vest fit prolonged tolerance and Ramirez et al. (1995) reported that the same vest reduced heat strain during exercise and recovery during exposure to hot/humid heat. Based on these findings, we sought to determine the effectiveness of the small 4-pack vest to reduce heat strain during actual shipboard firefighting activities.

Objective.

The purpose of this study was to determine the effectiveness of a 4-pack (5 lb) cool vest to reduce heat strain in naval personnel during shipboard firefighting activities.

Approach.

The fire tests (1992 Fleet Doctrine Evaluation Test Series) were developed by the Naval Sea Systems Command (NAVSEASYSCOM) and conducted by the Navy Technology Center for Ship Safety and Survivability, Naval Research Laboratory (NRL) aboard the Ex-USS Shadwell (LSD-15) located at Little Sand Island, Mobile, AL. Eight males served as subjects and participated in two tests. Measurement recordings included heart rate (HR), rectal temperature

(T_{re}), and skin temperatures from the upper chest (T_{ch}), upper arm (T_{ua}), thigh (T_{th}), and calf (T_{ca}). During the tests, subjects acted as fire investigators (n=2), safety monitors (n=2), and hose team members (n=4). Safety and hose team members dressed in the Navy FFE and oxygen breathing apparatus (OBA), while investigators wore gloves, rubber boots, flash hood, helmet, and OBA. During each test, half of the subjects wore the cool vest (CV) over their Nomex coveralls or, if they occupied the fire space, over their coveralls and underneath FFE, while the other half worn no vest (NV). Data from the two tests were combined. T-tests for independent groups were conducted to determine if changes in HR, T_{re} , T_{ch} , T_{ua} , T_{th} , and T_{ca} were significantly different between CV (n=8) and NV subjects (n=8). The significance level equalled 0.05.

Results.

Air temperatures during Tests 1 and 2 averaged 120°C and 105°C, respectively. Wearing CV during firefighting was associated with smaller increases ($p < .05$) in T_{re} and T_{ch} . Increases in T_{re} averaged $1.4 \pm 0.4^\circ\text{C}$ for CV compared to $2.2 \pm 0.8^\circ\text{C}$ for NV, while increases in T_{ch} averaged $3.3 \pm 1.2^\circ\text{C}$ for CV compared to $4.8 \pm 1.0^\circ\text{C}$ for NV. Increases in T_{ua} and HR responses were less for CV, but the differences were nonsignificant.

Conclusions.

Our findings demonstrate that the 5 lb 4-pack cool vest reduces heat strain during shipboard firefighting in air temperatures up to 120°C. The use of a torso cool vest as a countermeasure to heat strain has the potential to increase firefighting stay time of personnel during shipboard firefighter training and actual firefighting.

INTRODUCTION

Firefighting is a potentially dangerous activity due to unforeseen encounters such as extreme fire temperatures, steam, and lack of visibility. Navy firefighting is unique in comparison to municipal fire suppression because of the need to fight fires aboard ships and submarines containing many physical and logistical constraints. Furthermore, damage control teams must manage ventilation of heat and smoke and prevent contamination of other interior ship compartments. Foremost, damage control personnel must contain fires from spreading to other compartments affecting the ship's command and control operations or to areas containing munitions and other explosive materials so that ship survivability is not compromised.

During firefighting, naval damage control personnel wear the heavily insulated U.S. Navy firefighting ensemble (FFE) consisting of rubber boots, leather gloves, flash hood, hard helmet, single-piece fire retardant (Nomex) suit, and oxygen breathing apparatus (OBA). This ensemble is designed to give maximum protection without restricting mobility or the capacity to perform arduous tasks. However, the trade-off to body protection is a reduction in heat dissipation. Established procedures to reduce heat strain of hose team members include frequently rotating hosemen positions, and at set intervals replacing the primary hose team with a back-up hose team (Naval Ships Technical Manual NSTM 555, 1988).

Shipboard firefighting is associated with a significant level of individual heat strain as indicated by increases in heart rate to 200 bpm and body temperatures up to 40°C (Bennett et al., 1993a). Thus, investigations are needed to examine countermeasures to heat strain associated

with ship and shore fire training and actual shipboard firefighting. One approach which has the potential to reduce individual heat strain is the wearing of a passive cool vest.

Previous research has shown that a torso cool vest weighing 12 lb and consisting of 6 frozen gel packs can reduce heat strain in helicopter air crew personnel (Banta & Braun, 1992) and in personnel wearing FFE and performing low intensity exercise in warm air (Pimental et al., 1991). In addition, Bennett et al. (1993b) reported that the same 6-pack vest and a 4-pack vest reduced heat strain in individuals wearing FFE and resting and walking in warm/humid air. In this study, the 6-pack vest reduced heat strain to a greater degree than the 4-pack vest, however, the 6-pack vest did not fit snug under the FFE and was uncomfortable for individuals of short physical stature. In another study, Hagan et al. (1994) compared the effectiveness of large and small 4-pack cool vests to minimize heat strain in individuals wearing FFE and resting and exercising in a hot/humid environment. Both vests significantly prolonged tolerance time, however, the amount of heat strain reduction was similar between the two vests. The findings from this study served as the basis for a third study in which Ramirez et al., (1995) reported that the small 4-pack vest significantly reduced heat strain during exercise and recovery in personnel dressed in FFE. Thus, the finding from our laboratory studies suggested that the small 4-pack possessed the capacity to reduce heat strain during rest and exercise in hot/humid air. This vest also fit comfortably under the FFE thereby suggesting that this vest might be useful for training and live-fire operations.

The level of individual heat strain associated with shipboard firefighting emphasizes the need to evaluate methods minimizing heat strain in personnel performing firefighting activities. Finding an effective cool vest for shipboard firefighting requires the evaluation of torso cool vests which fit comfortably under the FFE, are lightweight, and possess the capacity to reduce heat strain during firefighting. However, cool vests have never been evaluated during active shipboard firefighting. It is unclear whether cool vests would reduce heat strain during this type of unique environmental stress. Therefore, the purpose of this study was to determine the effectiveness of a small 4-pack cool vest to reduce heat strain in naval personnel participating in shipboard firefighting activities.

METHODS

Fire Test Series.

The fire tests were part of the 1992 Fleet Doctrine Evaluation Test Series devoted to evaluation of current smoke and heat management doctrines during direct attack firefighting procedures. The tests were developed by the Naval Sea Systems Command (NAVSEASYS.COM) and conducted by the Navy Technology Center for Ship Safety and Survivability, Naval Research Laboratory (NRL). The tests occurred aboard the Ex-USS Shadwell (LSD-15), a decommissioned vessel used for damage control research, located at Little Sand Island, Mobile, AL (Carhart & Williams, 1988).

Subjects Volunteers.

Subject volunteers were active duty, U.S. Navy damage control personnel. Prior to the start of the test series, all subjects completed a medical history questionnaire. All potential subjects were screened for medical contraindications to firefighting by a medical officer prior to participation in this study. The study protocol was reviewed and approved by the Committee for the Protection of Human Subjects of the Naval Health Research Center. All subjects gave their voluntary consent, reviewed a privacy act statement, and signed an informed consent prior to participation. Body height and weight were measured using a standard medical scale. Body surface area (BSA) was calculated using height and weight according to a regression equation developed by DuBois (Carpenter, 1964). The physical characteristics of the subjects is presented in Table 1.

Table 1. Physical characteristics of the subjects.

| Subj. | Task | Age (years) | Height (cm) | Weight (kg) | BSA (m ²) |
|---------|--------------|----------------|----------------|----------------|--------------------------|
| 1 | Team Leader | 45 | 174.0 | 85.4 | 2.00 |
| 2 | Nozzleman | 26 | 182.9 | 113.2 | 2.34 |
| 3 | #1 Hoseman | 35 | 185.4 | 89.1 | 2.14 |
| 4 | #2 Hoseman | 29 | 180.3 | 89.5 | 2.10 |
| 5 | Investigator | 40 | 167.6 | 88.2 | 1.98 |
| 6 | Investigator | 34 | 171.5 | 66.8 | 1.78 |
| 7 | Safety | 41 | 175.3 | 61.4 | 1.75 |
| 8 | Safety | 34 | 180.3 | 90.4 | 2.10 |
| Mean±SD | | 35.5±6.3 | 177.2±6.1 | 85.5±15.8 | 2.02±0.19 |

Experimental Design.

Evaluation of the cool vest occurred over two fire tests. Two days separated the tests. During each test, physiological responses from 8 subjects were recorded. Subjects 1, 2, 3, and 4 were members of the hose team and included, in order of attack position, the team leader, nozzleman, and #1 and #2 hosemen, respectively. Subjects 5 and 6 were fire team investigators, and subjects 7 and 8 served as safety observers in the fire-space compartment.

During each fire test, 4 of 8 subjects wore a 4-pack cool vest (Steele, Inc., Kingston, WA 98346). The same subjects wore cool vests (CV) during each of the two fire tests. The 5 lb CV contained four frozen gel thermostrips. Each thermostrip weighed 15 oz. Two of the thermostrips were placed in vertical ThinsulateTM-insulated pockets on the front of the vest, while another two thermostrips were placed in horizontal pockets covering the back. The gel thermostrips were frozen to -28°C before use. During the fire tests, subjects wearing the CV were assigned similar responsibilities to a control (no vest, [NV]) subject, thereby, forming a matched pair. The paired subjects were in close proximity during firefighting activities.

Clothing Ensembles.

Fire retardant coveralls (Nomex) served as the undergarment for all subjects. During firefighting, safety and hose team members dressed in the standard Navy FFE. The FFE consisted of single-piece heavy insulated fire retardant suit, leather gloves, rubber boots, flash hood, hard helmet, and OBA. The investigators wore gloves, rubber boots, flash hood, helmet,

and OBA, but no FFE. The CV was worn over the coveralls for the investigators, and over the coveralls and under the FFE of the safety and hose team members.

Procedures and Physiological Measurements.

During the fire tests, heart rate (HR), rectal temperature (T_{re}) and skin temperatures from the upper chest (T_{cb}), upper arm (T_{ua}), thigh (T_{th}), and calf (T_{ca}) were recorded continuously for each subject by a Squirrel data logger (Science/Electronics, Miamisburg, OH 45342). Prior to each test, subjects inserted a rectal thermistor to a depth of 20 cm. Skin thermistors were placed over the right shoulder and upper right chest and middle of the right thigh and calf. HR was recorded using a bipolar chest electrode configuration. HR was also recorded using a electronic transmitter/receiver system (Polar USA, Stamford, CT 06902). The data logger was worn over the coveralls and underneath the FFE of the safety and hose team members.

Upon termination of each fire test, all subjects returned to the Mess deck and completed a questionnaire relating to each subjects' perception of physical exertion and thermal sensation during firefighting. Ratings of physical exertion (RPE) were determined using a 15-point scale (Borg, 1982). Ratings of thermal sensation (TS) were determined using a 8-point scale (Young, 1987) and included an overall body rating as well as seven local body areas (face, neck, chest, back, arms, legs, feet).

Test Protocol.

On the test days, all subjects attended a prefire meeting to discuss the fire suppression scenario. Subjects were then prepared for recording of physiological responses. After ignition of the fire and sounding of the shipboard damage control alarm, subjects dressed for firefighting on the ship's foc'sle. After dressing, subjects began firefighting activities. During each fire test, the team leader followed in order by the nozzleman, #1 hoseman, and #2 hoseman moved into the fire space. Prior to actual firefighting, two investigators (Subj. 5 and 6) searched for the fire, surveyed the fire area, and reported to Damage Control Central the location, size, and intensity of the fire. During each test, two safety officers (Subj. 7 and 8) occupied the forward Control/Interior Communications (CIC FWD) compartment and Control/Interior Communications after space (CIC AFT), respectively, to provide on-site safety monitoring. Termination of the test was followed immediately by a post fire brief to discuss desmoking and fire suppression methods and procedures.

Fire Test Scenarios.

The objective of the firefighting scenario was to extinguish a Class A wood crib fire in a small office in the Control and Interior Communications (CIC) compartment located on the 2nd deck. During the first test, a Class B diesel fire was ignited in CIC FWD to elevate the air temperature and create a high level of heat and smoke. The aim of the hose team was to enter CIC FWD through a starboard door, move through CIC FWD to the CIC office, open the office door, and extinguish the Class A fire with water. During the second test, a Class B diesel fire was ignited in CIC AFT again for the purpose of creating a high level of heat and smoke in the

compartment. In this scenario, the aim of the hose team was to enter CIC AFT through a port side door, and again advance to the CIC office to extinguish the Class A fire. The air temperatures in the CIC FWD (Test 1) and CIC AFT (Test 2) compartments during actual firefighting averaged 120°C and 105°C, respectively (Figure 1).

Statistical Analysis

Data from the two tests were combined for calculations of means and standard deviations and statistical analysis of the effect of CV on reduction of heat strain. Statistical analysis included t-tests of dependent physiological responses for independent groups (NV and CV). Significance was accepted at an alpha level of 0.05.

RESULTS

Effect of Cool Vest on Physiological Responses to Firefighting.

For NV and CV, the average firefighting exposure time was 41 ± 11 min. Baseline response obtained to dressing and firefighting and peak values of T_{re} , skin temperatures, and HR are presented in Table 2. Average T_{re} for hose team members during Tests 1 and 2 for CV (Subj. 2 and 4) and NV (Subj. 1 and 3) are shown in Figure 2.

The average peak T_{re} for CV ($n = 8$) of $38.6 \pm 0.3^\circ\text{C}$ was significantly lower ($p < .05$) than the average peak T_{re} of $39.3 \pm 0.8^\circ\text{C}$ for NV ($n = 8$). Also, the peak T_{ch} for CV averaged $38.5 \pm 0.8^\circ\text{C}$ which was significantly lower compared to the value of $39.8 \pm 1.5^\circ\text{C}$ for NV.

Table 2. Average rectal and skin temperature, and heart rate comparisons for NV and CV.

| Variable | Phase | No Vest | Cool Vest | Sign. Comp. |
|----------------------------|-----------|----------------|----------------|-------------|
| T_{re} °C | Pre-fire | 37.1 ± 0.2 | 37.2 ± 0.2 | n.s. |
| | Post-fire | 39.3 ± 0.8 | 38.6 ± 0.3 | $p < .05$ |
| | Δ | 2.2 ± 0.8 | 1.4 ± 0.4 | $p < .02$ |
| T_{ch} °C | Pre-fire | 35.0 ± 0.8 | 35.2 ± 0.8 | n.s. |
| | Post-fire | 39.8 ± 1.5 | 38.5 ± 0.8 | $p < .04$ |
| | Δ | 4.8 ± 1.0 | 3.3 ± 1.2 | $p < .02$ |
| T_{ua} °C | Pre-fire | 35.4 ± 0.8 | 35.3 ± 0.8 | n.s. |
| | Post-fire | 40.0 ± 1.3 | 38.9 ± 0.8 | n.s. |
| | Δ | 4.6 ± 1.2 | 3.6 ± 0.9 | n.s. |
| T_{th} °C | Pre-fire | 34.0 ± 1.6 | 33.6 ± 0.8 | n.s. |
| | Post-fire | 39.4 ± 1.2 | 38.5 ± 0.5 | n.s. |
| | Δ | 5.4 ± 1.2 | 4.9 ± 1.1 | n.s. |
| T_{ca} °C | Pre-fire | 34.2 ± 1.1 | 33.4 ± 0.8 | n.s. |
| | Post-fire | 39.6 ± 1.4 | 39.1 ± 1.0 | n.s. |
| | Δ | 5.4 ± 1.3 | 5.7 ± 1.6 | n.s. |
| HR (bt•min ⁻¹) | Pre-fire | 76 ± 9 | 86 ± 10 | n.s. |
| | Post-fire | 185 ± 19 | 178 ± 15 | n.s. |
| | Δ | 109 ± 18 | 92 ± 18 | n.s. |

Wearing the CV was associated with significantly smaller increases in both T_{re} and T_{ch} (Figure 3). For CV, increases in T_{re} averaged $1.4 \pm 0.4^\circ\text{C}$ compared to $2.2 \pm 0.8^\circ\text{C}$ for NV. For CV, increases in T_{ch} averaged $3.3 \pm 1.2^\circ\text{C}$ compared to $4.8 \pm 1.0^\circ\text{C}$ for NV. Increases in T_{ua} and HR were also less while wearing the CV, but the differences were nonsignificant.

Effect of Cool Vest on RPE and TS.

The results of the postfire test questionnaire indicated that perception of TS for the chest, back, and overall body were significantly lower in CV compared to NV. However, TS for the head, face, neck, arms, hands, legs, and feet were similar ($p > .05$) for CV and NV conditions. RPE was similar ($p > .05$) for both conditions (13 ± 1 for CV and NV).

Table 3. Average values from Tests 1 and 2 for regional and overall thermal sensations.

| Thermal Sensation | No Vest (n=8) | Cool Vest (n=8) | Significant Comparisons |
|-------------------|------------------|--------------------|-------------------------|
| Overall | 5.5 ± 1.3 | 4.4 ± 0.9 | p < .05 |
| Chest | 4.7 ± 1.0 | 3.2 ± 0.7 | p < .05 |
| Back | 4.9 ± 0.9 | 3.1 ± 0.9 | p < .05 |
| Face | 4.7 ± 0.8 | 4.6 ± 0.8 | n.s |
| Neck | 5.0 ± 0.9 | 4.8 ± 0.9 | n.s |
| Arms | 5.6 ± 1.0 | 5.1 ± 0.6 | n.s |
| Legs | 5.2 ± 1.3 | 5.1 ± 0.7 | n.s |
| Hands | 5.7 ± 1.1 | 5.7 ± 0.9 | n.s |
| Feet | 4.8 ± 1.1 | 4.5 ± 1.0 | n.s |

DISCUSSION

Baseline HR values averaged $80 \text{ bt} \cdot \text{min}^{-1}$ for NV and CV, while active firefighting produced average peak HR responses of 179 bpm for both NV and CV. The peak HR values observed during these tests were similar to values previously recorded for naval personnel combating shipboard fires (Bennett et al., 1993a). These values also are comparable to those reported for municipal firefighters engaged in actual firefighting (Barnard & Duncan, 1975) and

men engaged in firefighting training activities (Romet & Frim, 1987). Since the movements of our firefighters were confined to passageways and the CIC compartments, the lack of difference in HR between CV and NV may be due to several factors. These factors include the role of central command in the control of HR (Mitchell, 1990), similar skin blood flow and heat dissipation requirements (Rowell et al., 1969), impact of body position (kneeling on bent knees during firefighting to get under the high-temperature isotherms) on venous return and blood pressure during active firefighting, and high compartment temperatures. Thus, under these conditions, CV had no effect on maximum HR response. This finding is supported by findings from other studies showing that the small 4-pack CV had no impact on HR during rest, exercise, and recovery in hot/humid heat of 48°C and 65% relative humidity (Hagan, et al., 1994; Ramirez et al., 1995).

Firefighting while wearing the 4-pack CV underneath the FFE resulted in significantly smaller increases in T_{re} . Figure 2 illustrates the impact of CV on T_{re} of the hosemen during the two tests. Firefighting also resulted in significantly smaller increases in T_{ch} . The thermocouple recording T_{ch} was not directly under vest pockets holding gel-packs. Thus, the lower T_{ch} is related to CV coverage to the torso area. Smaller increases in T_{ua} for CV compared to NV were also observed, however, the differences were not significant. The lack of difference in T_{th} and T_{ca} between CV and NV suggests that the effect of CV is confined to the upper body. This finding is similar to the findings of Ramirez et al. (1995) who reported that use of the small 4-pack CV was associated with significantly lower T_{ch} and T_{ua} .

Postfire test questionnaires indicated that naval personnel felt that the CV reduced their heat strain during firefighting. This perception can be explained by the ability of CV to reduce T_{re} and upper body skin temperatures. The significantly lower T_{re} , T_{ch} , and near-significant lower T_{ua} and HR observed for CV suggests that the 4-pack cool vest can reduce heat strain in personnel conducting firefighting activities. This may protect firefighters from excessive heat strain and avoid heat illness. Thus, our findings suggest that a torso cool vest will reduce T_{re} and upper body temperatures during shipboard firefighting activities in compartment temperatures up to an average temperature of 120°C.

SUMMARY

In conclusion, we have documented the effect of a passive microclimate cooling device on heat strain reduction, as indicated by lower T_{re} and T_{ch} , in naval personnel during actual shipboard firefighting. The near-significant lower peak HR is also suggestive of lower heat strain with CV. Dressing in the standard Navy FFE and OBA, performance of preparatory firefighting activities, and execution of actual firefighting procedures produced a high level of individual heat strain. However, the 5 lb 4-pack cool vest reduced heat strain. The use of the 4-pack cool vest during firefighting was characterized by: 1) lower increases in T_{re} and T_{ch} ; 2) lower peak T_{re} , T_{ch} ; and 3) a lower perception of overall body and torso TS. Since this torso cool vest has the capacity to reduce heat strain, it may also contribute to a lower heat strain and incidence of heat illness, and to an extension of firefighting stay time. Torso cool vests of similar size and fit, but capable of holding larger-sized gel packs may have a greater impact on the prevention of heat

strain during firefighting. Consideration should be given to incorporating additional frozen gel packs possibly to the arms and legs to further reduce heat strain.

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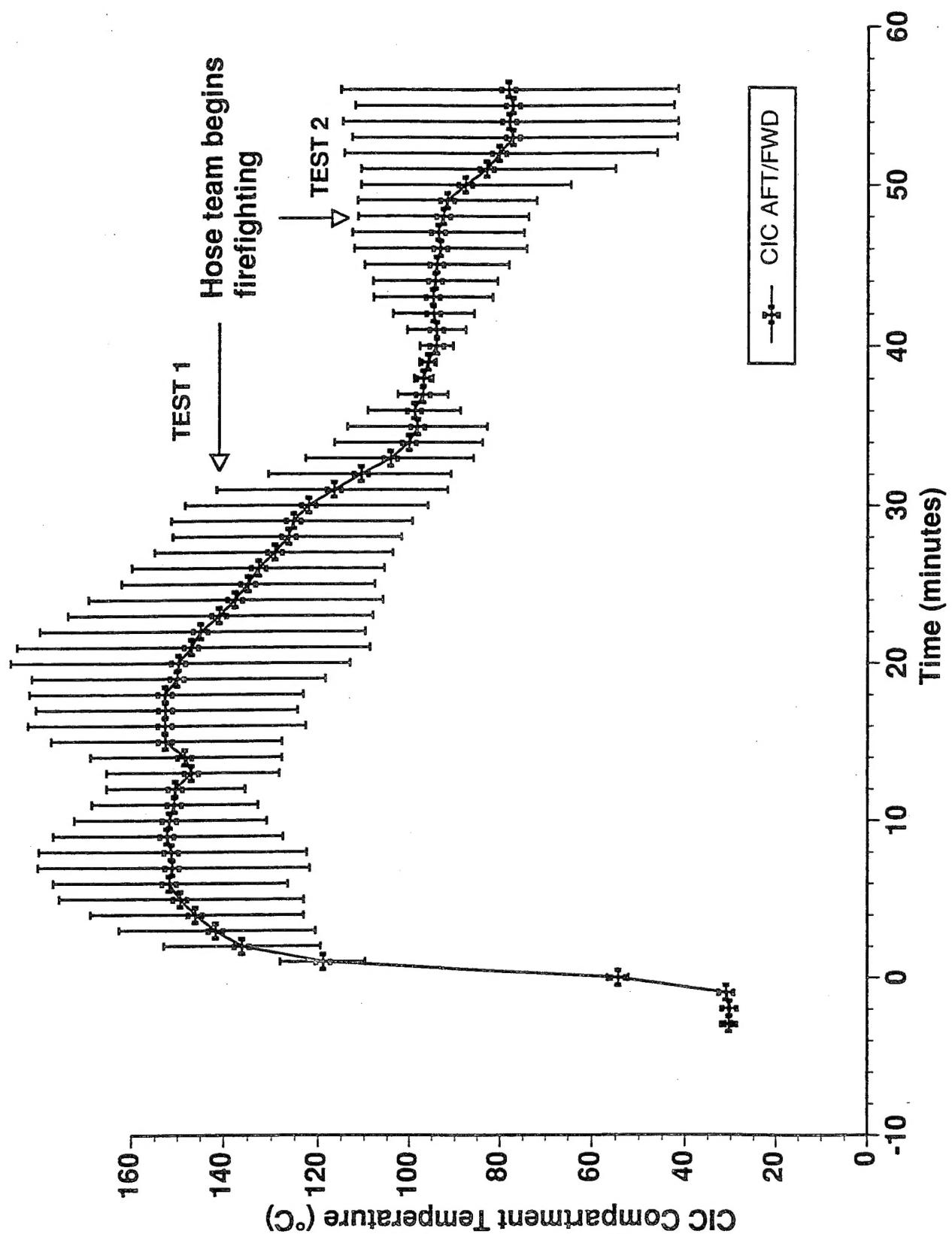


Figure 1. Average CIC compartment air temperatures during Tests 1 and 2.

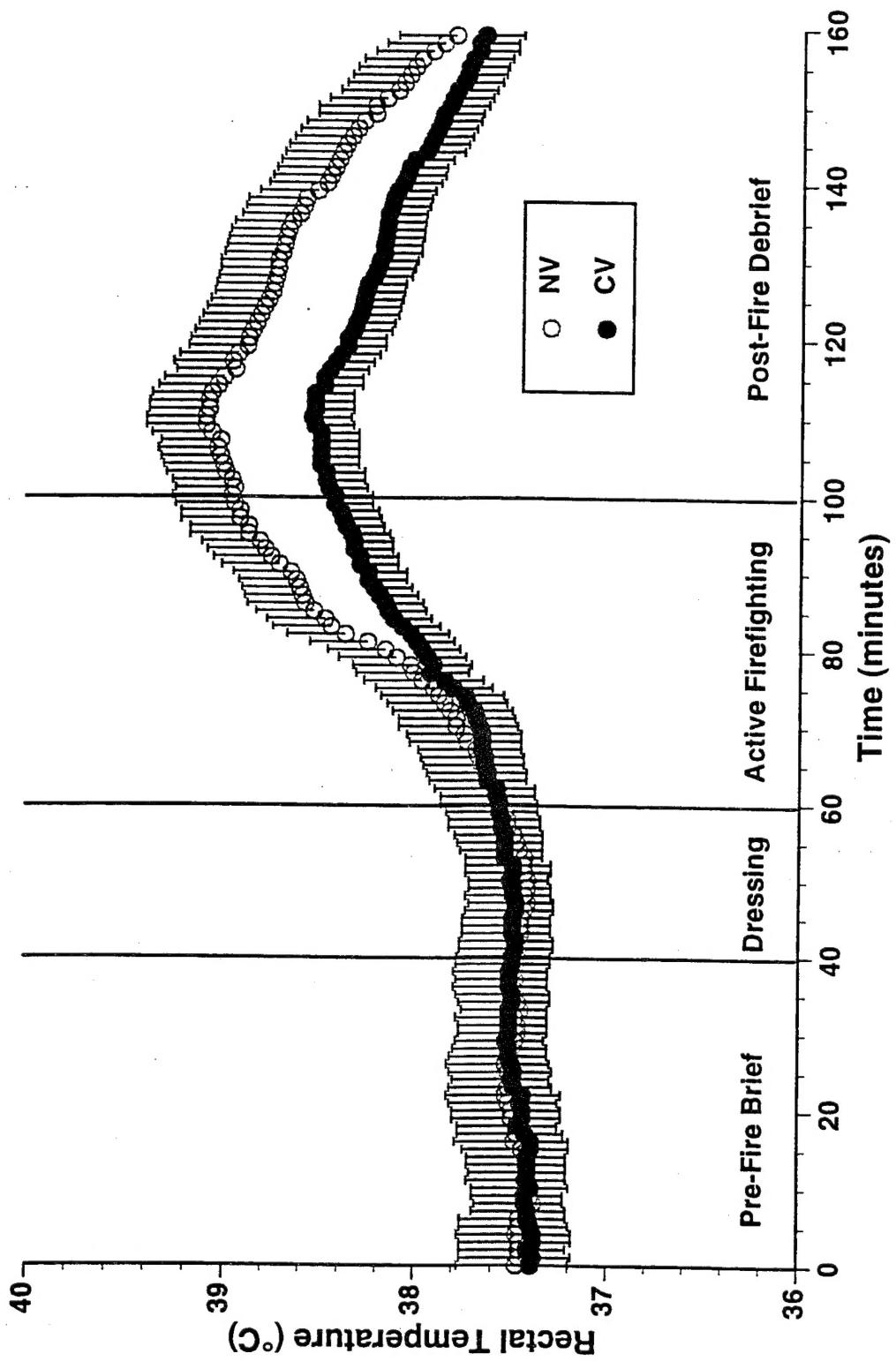


Figure 2. Average rectal temperature from Tests 1 and 2 of hose team members for NV ($n = 4$) and CV ($n = 4$).

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| <p>The use of a 6-pack (12 lb) cool vest (CV) can reduce heat strain in personnel wearing firefighting ensemble (FFE) and exercising in air temperatures under 37.8°C (100°F). However, the 6-pack CV does not fit comfortably under the FFE. Thus, the purpose of this study was to determine the effectiveness of a 5 lb 4-pack cool vest (CV), compared to no vest (NV), to reduce heat strain in personnel performing firefighting activities during fire tests aboard the Ex-USS Shadwell (LSD-15), Mobile, AL. Eight males served as subjects. Measurements included rectal (T_{re}), skin temperatures from the chest (T_{ch}), upper arm (T_{ua}), thigh (T_{th}), and calf (T_{ca}), and heart rate (HR). Air temperatures in the fire space averaged 120°C (248°F). For all subjects, dressing in FFE and execution of pre-firefighting activities led to gradual increases in HR, T_{re}, and skin temperatures. During actual firefighting, HR, T_{re}, and skin temperatures rose rapidly in all subjects. However, wearing CV was associated with smaller increases ($p < .02$) in T_{re} and T_{ch}. Our findings indicate that the use of a 5 lb 4-pack CV has the potential to reduce heat strain and increase firefighting stay-time of naval personnel during training and actual shipboard firefighting.</p> | | | |
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| Heat strain, torso cool vest, shipboard firefighting | | 22 | |
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| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
| Unclassified | Unclassified | Unclassified | Unlimited |